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What's With the Weather?

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Introduction

Most crops are well adapted to the prevailing climate. Nevertheless, weather remains the most significant factor in successful crop production. Weather-wise management of production and marketing can greatly reduce the risk of crop loss and of financial failure in crop production. The cyclic nature of midwest weather, the relationship of potential yield to soil moisture, and the effects of temperature on the development of crops and crop pests should be understood by the farmer and by the farm service representative.

Corn yield in Iowa and Illinois improved slowly during the first half of the 20th century. There was considerable yield variation from year to year because of weather and pests, but improvement was, overall, consistent. From 1955 to 1971, the yield trend improved rapidly and year-to-year variability was small. Some attributed the improvements to land management and some to greatly improved hybrids. Even the consistency from year to year was thought by some to indicate that modern hybrids were not greatly affected by the year-to-year variations in the weather. Whatever the reason, consistent yields ended with the onset of wide-spread corn disease in the early '70s and the spread and success of the disease itself was weather oriented. Year-to-year variability since 1972 has been as great as it was during the years before 1955.

Subsoil Moisture

Iowa soils are generally considered capable of holding 10 inches of plant-available soil water in the top 5 feet of soil. Sandy soils, of course, hold significantly less and some soils may hold slightly more. During July and August, rainfall is seldom sufficient to fully satisfy crop needs and supplemental moisture from the soil profile is needed for the crop to meet its water demands and achieve the yield potential.

Subsoil moisture is measured in early April and late October across Iowa. A generalized moisture map is published as of November 1 and April 15 each year. Throughout the crop season, rain and evaporation measurements are used to compute the quantity of water retained in the subsoil. The fall 1991 survey showed that soil moisture was near normal in most of Iowa. The plant-available water was near or above normal in 70 of Iowa's 99 counties. Below-average areas were mainly within 1 or 2 inches of normal and could be improved to average by one significant rainfall event. Near 8 inches of plant-available soil moisture is considered favorable.

As soil moisture becomes low, the crop cannot withdraw enough water to satisfy demands on stressful (hot, windy, dry) days. When 4 inches of plant-available moisture remain in the soil, corn leaves are rolled by 10 or 11 A.M. on sunny days. Plants usually recover soon after sundown. Midday wilting or leaf rolling may slightly reduce the development and growth of the crop. When 2 or 3 inches of water remain in the soil, the leaves will often stay rolled throughout the 24-hour period, and there may be some reduction in crop surface area; soybeans and corn tend to abort more of their lower leaves under harsh conditions. Some of the leaves may begin to "fire" and be lost. When moisture is reduced to 1 or 2 inches of plant-available water in the soil, the plant ceases to grow, although it may remain alive and able to transfer foodstuffs from the stems and roots to the grain, if grain has begun to form.

Water use by the crop is complex. Some rules and numbers are needed to estimate the water use by the crop and the amount of water that is left in the soil. There is a maximum amount of water that a crop can use. The maximum is determined by the atmospheric conditions and by the type and condition of the crop. The maximum amount is known as the "potential evapotranspiration." If the actual amount of water used is equal to the potential, there is no water stress and no stress-related loss of yield.

The potential evapotranspiration of the crop is very small when the crop is emerging and reaches a maximum when the crop has maximum leaf area. Atmospheric effects determine the amount of water that will evaporate from a pan of water; this is known as the "pan evaporation." The crop stage effect is multiplied by the pan evaporation to give the potential evaporation. At emergence, the soil and plants evaporate about 0.3 of the pan evaporation. In Iowa, a corn field after silking has the potential to transpire about 0.83 of the pan evaporation. A soybean field at full leaf (60-70 days after planting) will use 1.1 times the pan evaporation. Pan evaporation can exceed 1/3 inch during mid-summer.

As a guide to the potential crop water use, the following crop stage factors may be used:

Factor	Date/Stage
Corn	
0.3	emergence
0.6	July 1
0.75	July 15 to silk
0.83	after pollination
Soybean	
0.6	40 days after planting
0.9	60 days after planting (when canopy closes)
1.1	70 days through leaf turning

If the pan evaporation is 0.3 inch on July 15, corn will potentially use about 0.3 * 0.75 = 0.225 inches of water. By mid-July it may be assumed that corn uses about 1/4 inch of water per day.

When soil moisture is not ideal, the evapotranspiration will be less than the potential. As a rule of thumb:

Corn leaves rolled by 10 A. M.	0.5
Leaves rolled all day	0.25
Plants wilted, leaves firing	0.10

Thus, if leaves are rolled on July 15 and the pan evaporation is 1/3 inch, the water use by the corn crop is: 0.33 * 0.75 * 0.25 or 0.062 inches of water. Pan evaporation in July is normally 7.75 inches for the month in north Iowa and 8.75 inches in the southwest. The record is about 12.1 inches for the month. These values translate to about 1/4 inch of water per day in the north and 0.28 in the southwest. During the record month the pan evaporation was close to 0.4 inches per day.

It is uncommon for a crop to use the potential amount of water because soil moisture is normally somewhat limiting. In northwest Iowa the July potential for corn averages 6.3 inches of water but the average actual amount of water used is 5.5 for the month.

Crop yields in Iowa can be anticipated by assuming that water is the limiting resource. If the growing season is not shortened by freezing temperatures and there is not an abnormal number of damaging storms, diseases or crop pests, the yield reduction is proportional to the difference between the potential evapotranspiration and the actual water usage.

Degree Days

The "growing degree day" is a simple measure of the accumulated temperature effect on the development of corn and of some other crops and crop pests. The National Weather Service Growing Degree Day is based on a 50°F threshold. Several other degree day methods have been formulated and bases have been defined for other crops and pests. Only the National Weather Service method will be described here, as it is the one most generally available to the crop producer.

Corn grows when the temperature exceeds 50°F. Growth may be hampered by temperatures in excess of 86°F. Crop developmental stage is closely correlated with the occurrence of favorable temperatures.

Corn degree days are calculated by averaging the high and low daily temperatures and subtracting 50. If the low temperature is less than 50°F, it is assigned the value of 50 degrees. If the high exceeds 86° F, it is assigned the value of 86 degrees. Degree day values are accumulated throughout the growing season. Degree days may not have a negative value.

The average annual growing degree day accumulation for Iowa ranges from about 3100 in north Iowa to near 3900 in the South. If the degree days before May 1 and those after September 30 are neglected, the range is 2600 through 3300. Degree day records often begin by March 1 and represent all growing weather for the crop year including that portion before planting. The records are useful in evaluating the development of weeds and insect pests that are influenced by the early season conditions. The crop producer will need to note the accumulation at the time of planting to utilize such records for anticipation of developmental stages for the crop. Sometimes a degree day record begins April 1 to represent the accumulation for corn planted on the average date. To use the latter, a producer must estimate the degree days before April if the crop was planted early or note the total if planted later.

The average degree day accumulation for two locations that reach 2800 growing degree days within 4 weeks of each other may only vary by one week when 1400 degree days are accumulated in mid July. A rule of thumb is: if growing degree days are one week behind normal in early August, a crop maturity delay of two to four weeks may be anticipated. Factors of day length and seasonal heating make it possible for a degree day deficit early in the season to "catch up," but when the accumulation is behind after the first of August, substantial catching up is unlikely.

The development stages of corn and of several pests can be anticipated according to degree day accumulations. Because not all plants and insects begin development at 50° F, it is necessary to calculate growing degree days for some "bases" other than 50° F.

Degree Days and Cloudy Days

The degree day assumes that a more or less regular relationship between temperature, sunlight, and other factors important to crop development exists. When conditions are extreme, such as the rainiest season on record or the cloudiest summer, etc., this assumption is not valid and the development of a crop or pest may not be strictly described by the degree day accumulation. Sunshine, for example, will often cause leaves to heat somewhat above air temperature in Iowa. When a season is exceptionally cloudy, the actual temperature of the plants may average much less than would be expected from the degree day total and the biological development may be substantially influenced.

Heat Stress

Heat stress is often cited as a reason for poor crop development or yield. Strictly speaking, heat stress is seldom if ever a factor in Iowa crop production. Most plants are not adversely affected by heat itself until temperatures rise to well over 100 degrees. Corn develops best at temperatures in the mid 90s if sufficient water is available. When there is not sufficient water available to the plant or wind and other conditions are such that the plant cannot obtain water in sufficient quantity to meet demands, stress conditions develop. Under this water stress, often associated with hot weather, the plant is not able to develop at its full potential. On the average, Iowa soil water availability is such that temperatures in excess of 86°F may be considered as stressful.

Crops are very sensitive to heat stress during the month of July. If heat stress degree days are computed (86°F is the base and no maximum temperature considered), a negative correlation is found between yield and stress degree days. The period of little variability in yield that was noted between the mid-fifties and the early seventies was a period of little mid-season heat stress. Later years have been more typical of conditions during the first half of this century.

Cycles- El Niño- Climate Change

Cyclic weather conditions influencing the yield of midwest crops have been known since 1885. By the 1930s, an 18- or 19-year cycle was generally known. The cycle has been identified as 18.6 years, a time identical to the cyclic gravitational influence of the moon's orbit. The cycle includes a period of about 6 years when weather conditions are usually favorable for crop production and 6 years when weather is uncertain. The risk of Corn Belt-wide drought is greater during the 6 years of uncertainty. Often there are very favorable years during the uncertain interval, but 60% of all widespread droughts in the midwest develop during the years of uncertainty. Normally one or two serious drought conditions will develop during the 6-year interval.

A majority of widespread droughts have developed in the year following a South American weather event known as El Niño. However, not all El Niño events are followed by a drought. The El Niño may be classified as strong or weak depending upon the deviation of the ocean temperature from average in the El Niño region (between the west coast of South America and Australia and within 10 degrees of the Equator). Strong events are more likely to be followed by an anti-El Niño (sometimes called La Niña) which tends to encourage drought conditions in the Corn Belt. When the anti-El Niño occurs during the "uncertain" years of the 18.6 year cycle, the development of a drought is likely.

The duration of an El Niño is not predictable. Most El Niño events persist at least 6 months and some longer than 18 months. An anti-El Niño effect may develop some 3 to 6 weeks following the end of an El Niño event. Some scientists feel that volcanic activity near the equator will strengthen El Niño events.

The El Niño does not develop at a regular interval. Some have come as quickly as the second year following the end of one El Niño event and some after as long as 7 years. The average is 4 or 5 years. The El Niño developed in 1982, in 1987 and again in the fall of 1991. The 1991-92 El Niño appeared to have ended by early October (1992).

Following the 1991-92 El Niño it is likely that a widespread drought will develop within the Corn Belt. The statistical probability is about 70%. A drought could develop early or late in the growing season of 1993; however, since the El Niño persisted only until fall of 1992, the development of drought in the spring of 1993 is the more likely possibility. Because 1993 is the end of the uncertainty portion of the 18 year cycle it is possible that the central United States may escape further serious droughts during this century. The next interval of uncertain weather conditions will begin in the year 2005. Some have cautioned that the Green House Effect may significantly influence the harshness during the next period of uncertainty.

Climatologists have long understood the "Green House" effect of carbon dioxide and other gases. The natural green house effect is assumed to result in the average temperature of the Earth being some 15°F warmer than it would be without the effect. Without the natural green house effect, the midwest would likely be an area where the lakes never thawed and the frost never left the soil. During the past century, human activities have been releasing substantial amounts of carbon dioxide and other green house gases into the atmosphere. Many scientists caution that the human activity may have global impact on the energy balance of the Earth and may modify the climate in ways that are not entirely desirable.

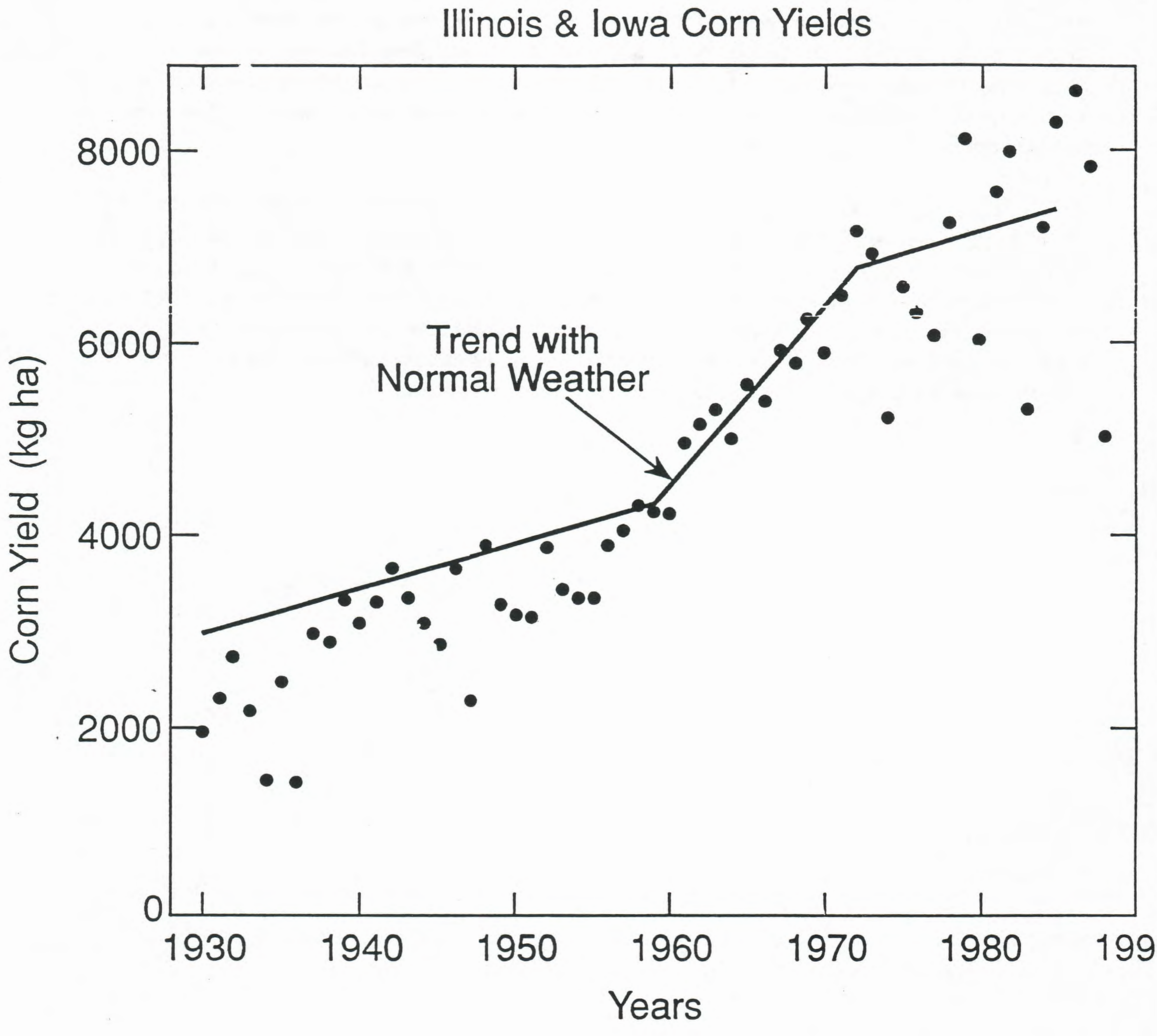
Data collected since 1957 show that the carbon dioxide is indeed increasing significantly. Also, the concentration of other green house gases released by human activity is clearly increasing. The effect of the materials upon the Earth's climate is not yet fully understood nor readily apparent. Researchers point to the "Ozone Hole" as a possible indicator that gases used in refrigeration are already having a global impact. Freon used as a refrigerant is a strong green house gas. Worldwide average temperatures may be influenced by the green house effect.

During the past century, there has been an apparent warming of the Earth. The warming is indicated by averaging the temperature recorded at all the Earth's weather stations. The stations where cities have invaded the site and may have caused local warming have been removed from the evaluation. The bulk of the weather stations used in the worldwide average are in Europe; accordingly, the average does not necessarily reflect a true global trend. When only the data from the United States of America are considered, no warming trend is seen at this time. Inspection of the world trend shows an increase in temperature from 1880 through 1940 followed by a period of global cooling. The warming trend resumed in the 1970s.

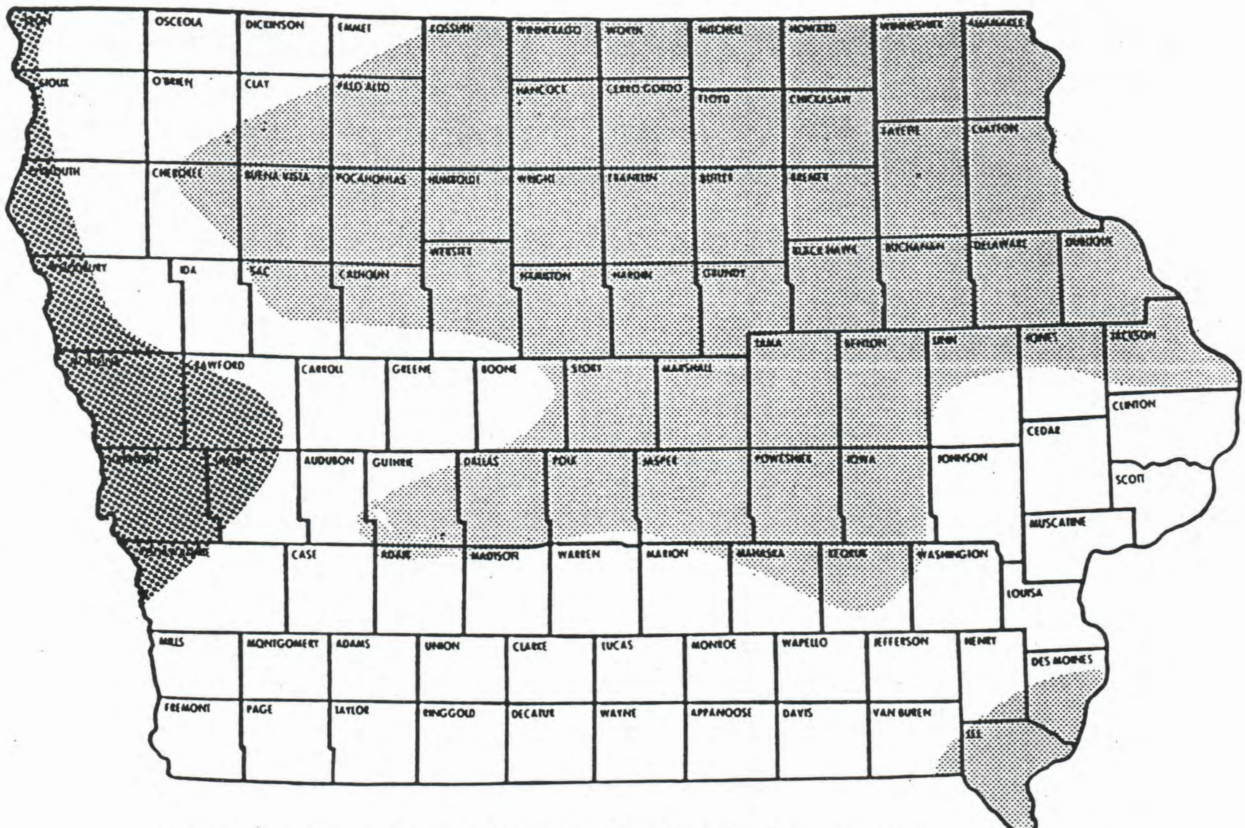
Interpretation of the global temperature record is not uniform throughout the scientific community. Some feel that the trend is natural and little influenced by human activity. Others feel that the warming is a result of man's activity. During the 1960s there was considerable speculation and concern about the cooling trend; human industrial and agricultural activity was thought to be contributing dust and haze to the atmosphere to the extent that the world climate might cool to disastrous levels. The return to warming led the speculators to assume that the gases produced were counter and more disastrous than the haze effects.

Climatologists have reported that few of the effects predicted by those cautioning against allowing the "man-made green house" to continue have been detected. However, some effects that may be green house related are being observed: Spring-like weather is developing at an earlier date in widespread regions and the development of fall weather patterns is not changed. High level cloudiness is increasing markedly in the southern hemisphere. The year-to-year variability of weather conditions is increasing. The undulations of the arctic front have become more extreme, causing greater week-to-week variation in temperature and precipitation than usual in the temperate zones of the Earth.

The pattern of year-to-year variability of heat stress on crops in Iowa correlates with the global temperature trend. During the period of heating from 1880 to 1940, variability was high. During the global cooling period, stress was reduced and variability reduced as a supposed result of more stable weather patterns. When global heating resumed, the stress variability again began to increase. Although the correlation may be more coincidental than cause and effect, one cannot help but speculate that the variability that has been increasing during the past few years will continue and may be a primary manifestation of the "green house."


Illinois & Iowa Corn Yields
Trend with
Normal Weather
Corn Yield (kg ha)
8000
6000
4000
2000
0
1930
1940
1950
1960
1970
1980
199
Years

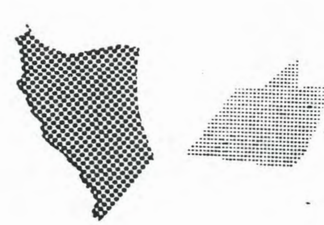
Subsoil Moisture 1 November 1991



Source: ES Cooperative Extension Service, Iowa State University, Ames, Iowa 50011

- 8-11 inches
- 4-7.9 inches
- less than 4 inches

Subsoil moisture measured for 1 November 1991 was near normal in most of Iowa.
Soil moisture was near or above normal in 70 of Iowa's 99 counties. Below average areas were mainly within 1 or 2 inches of normal and could be improved to average by one significant rainfall event. Near 8 inches of plant available soil moisture is considered favorable. Values are for the top 5 feet of soil.



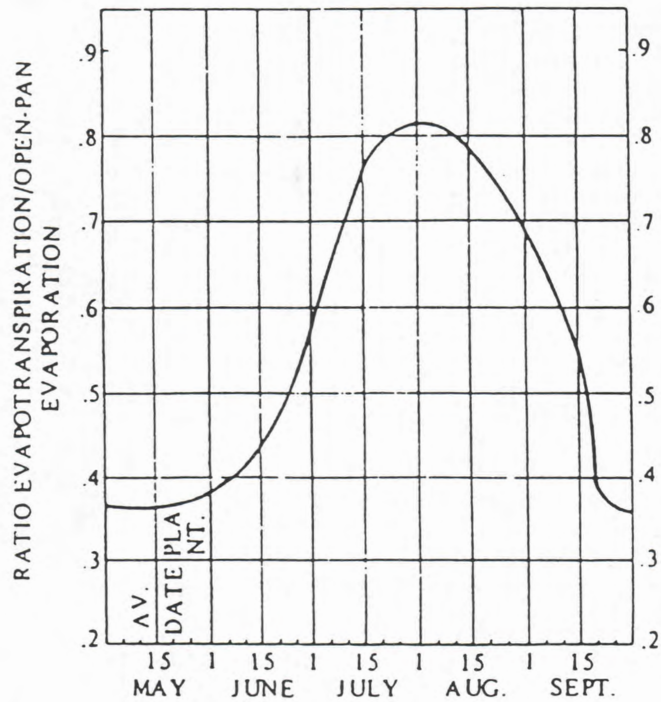
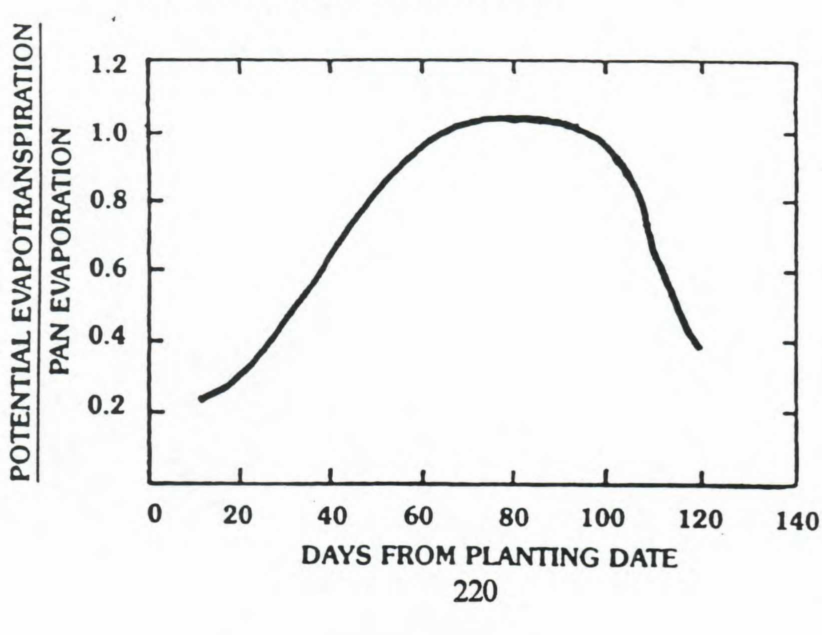
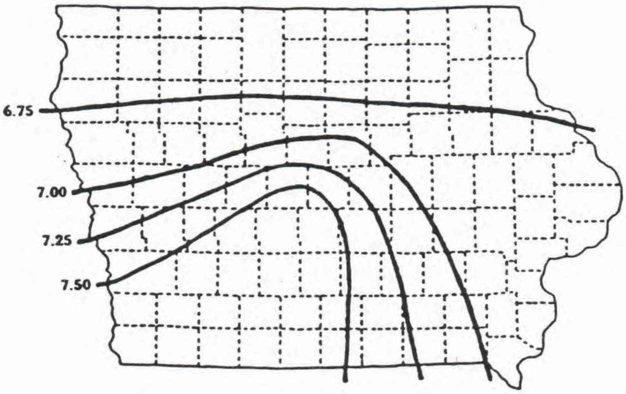


Fig. Ratio of evapotraspiration of corn to open-pan evaporation throughout the growing season (after Denmead and Shaw, 3). On the average, 50% of the corn in Iowa is silked by July 31.

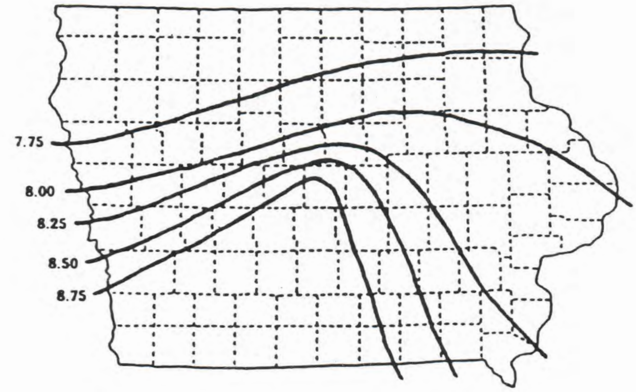
Figure ***Potential evapotranspiration/pan evaporation ratios for combined soybean varieties Hark and Rampage as a function of days from planting.***



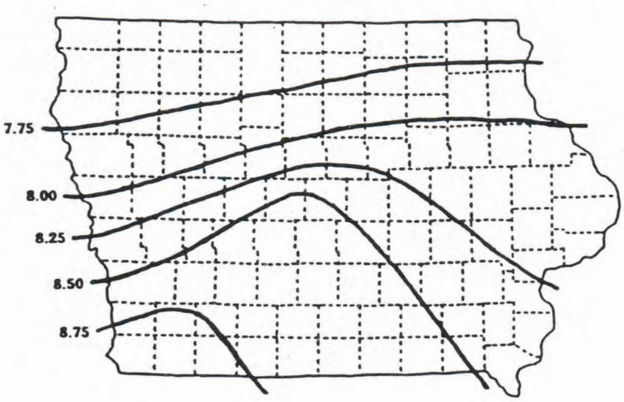
May Pan Evaporation



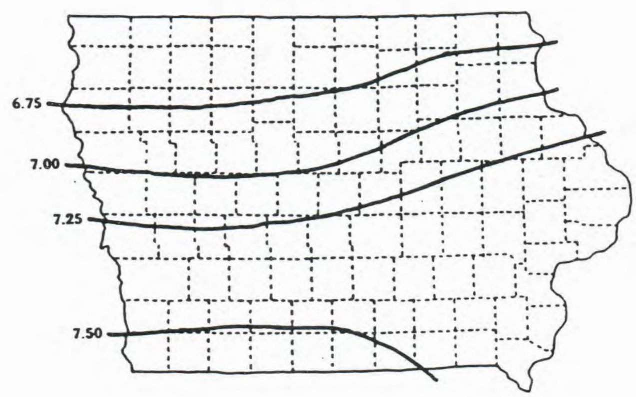
June Pan Evaporation



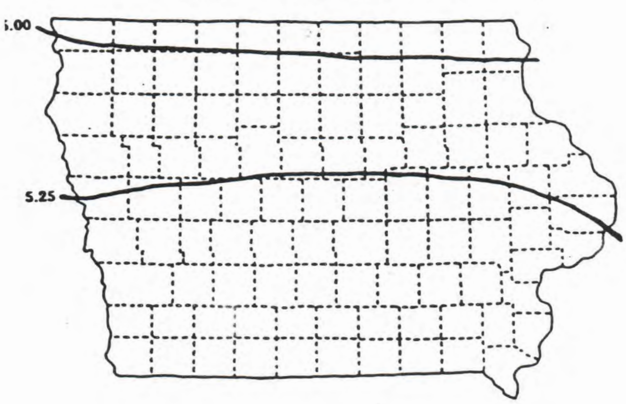
July Pan Evaporation



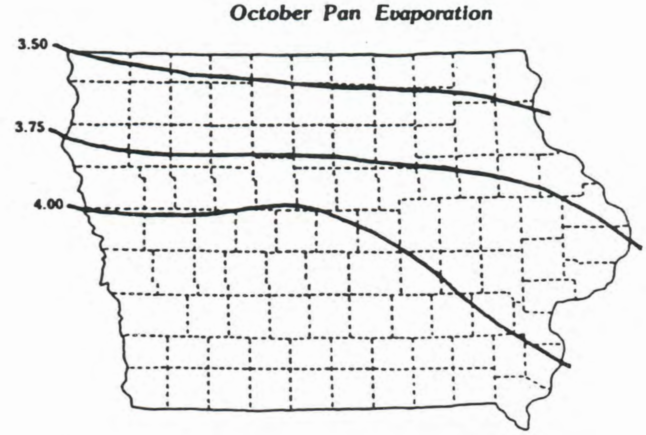
August Pan Evaporation



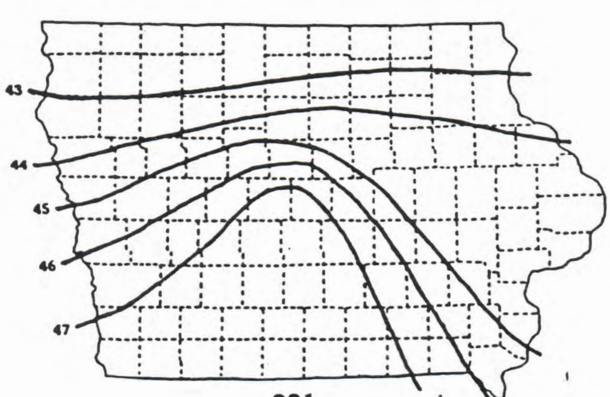
September Pan Evaporation



October Pan Evaporation



Seasonal Pan Evaporation



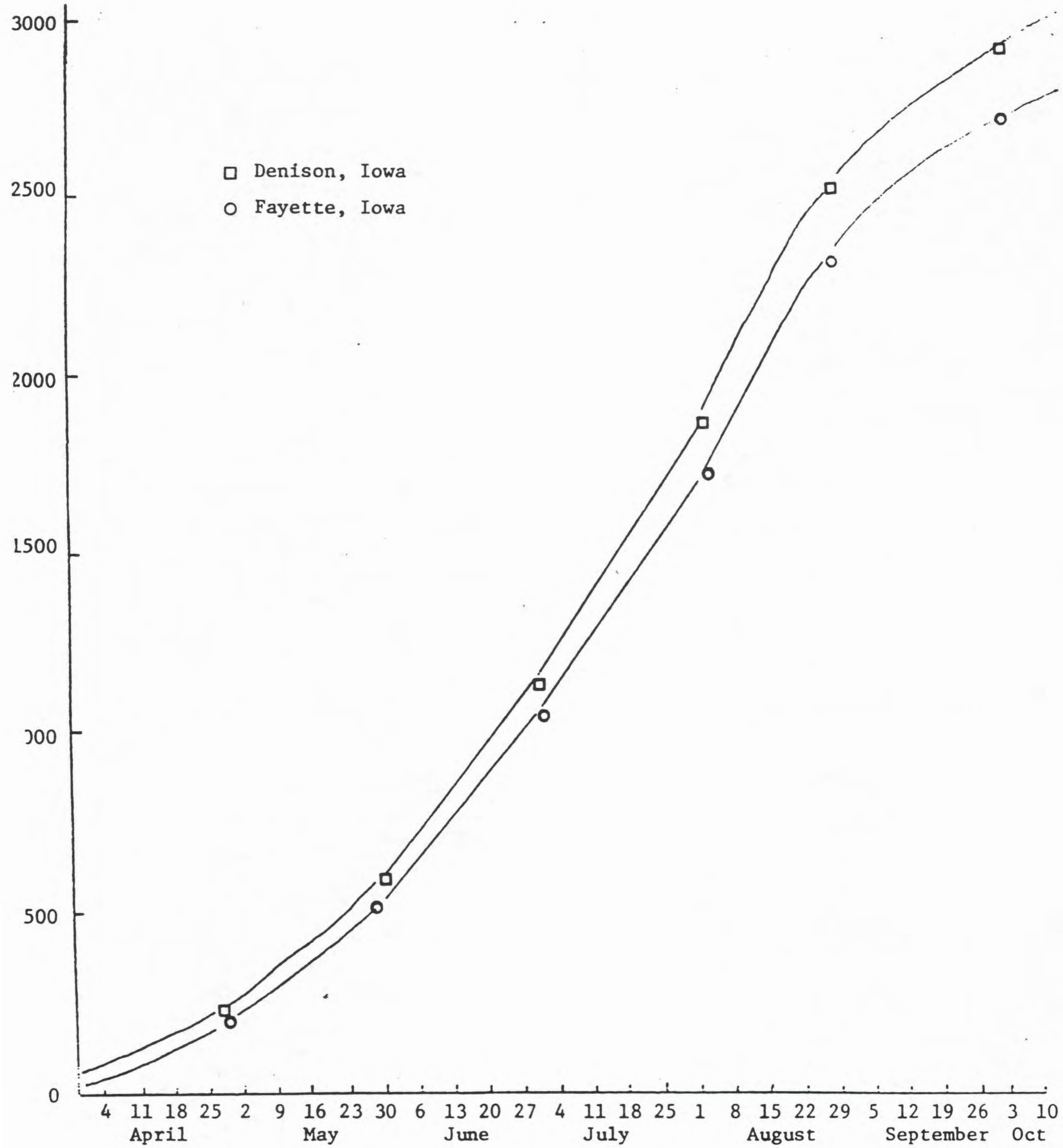


Figure . Growing degree day accumulation according to week for two Iowa locations. If current values are plotted on the chart the curves serve as a reference for evaluation of seasonal crop developmental progress.

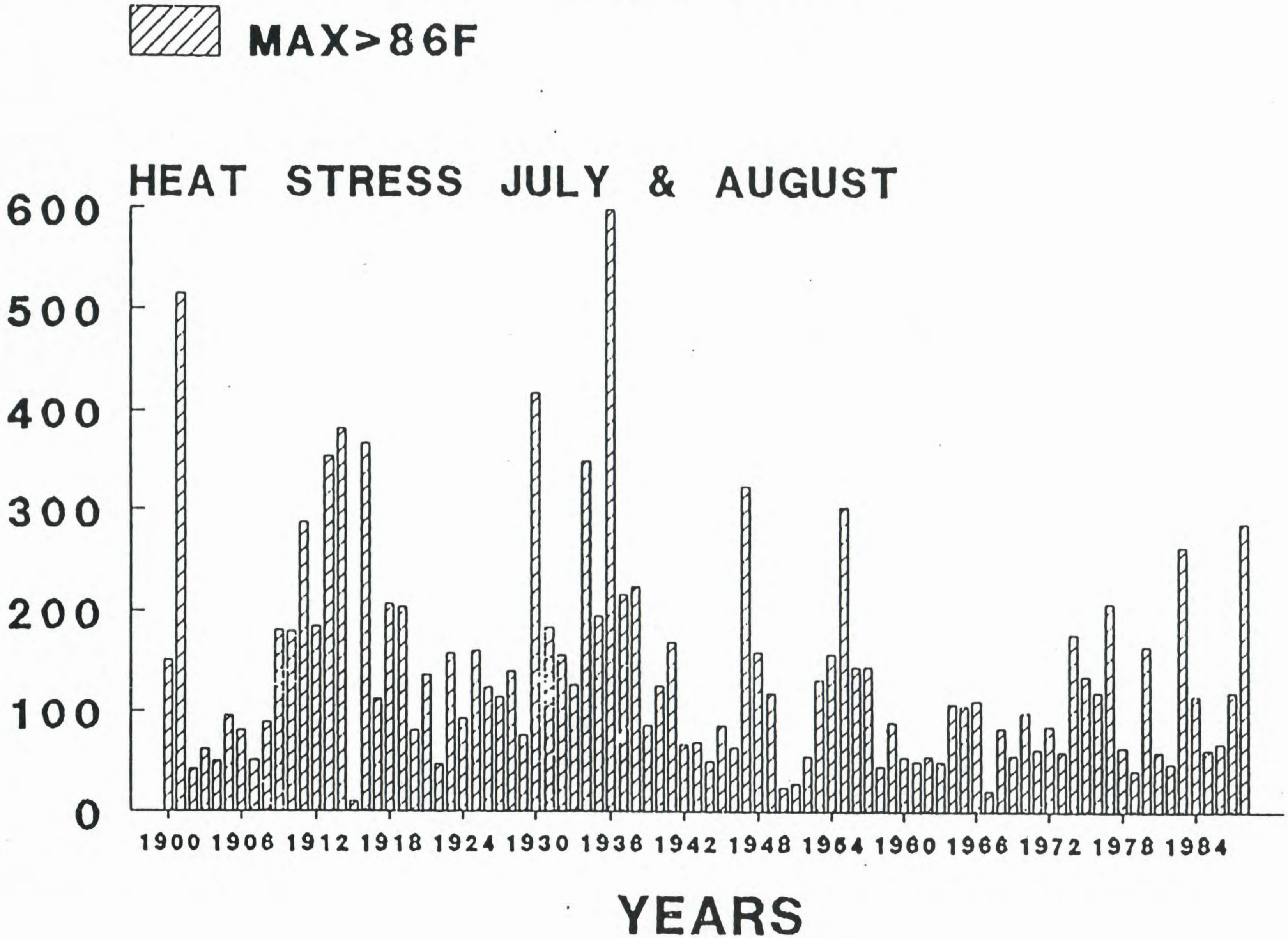
Table 1. Stages of development according to degree day accumulation. Degree days are computed according to "base" temperature appropriate to specific crops or pests.

DD	Corn*	Corn Borer	Black Cutworm	Alfalfa Weevil DD	Rootworm DD
0					
100					
200			1st moths		
300	Plant			Egg hatch	
400		Moths			
500			1st cutting		
600		Egg laying			
700		Egg hatch	6th instar	End	
800					
900			7th instar		Hatch
1000			End cutting		
1100					
1200					
1300					
1400		Pupate			Damage
1500					
1600	Silk				
1700		Moths			
1800					
1900		Egg hatch			Adults
2000					
2100					
2200	Dough				
2300					
2400					
2500	Dent				
2600					
2700	Mature				
2800					
2900					
3000					New eggs

*Average of all Iowa varieties.

Stress degree days may be computed much as growing degree days but 86 is used as the base temperature. In Iowa (Figure 9) average annual stress is some 3 to 4 times greater in the west than in the east portion of the state. It should be noted, however, that temperatures near 90°F may not actually cause stress if soil water is ample, humidity is high and wind is low.

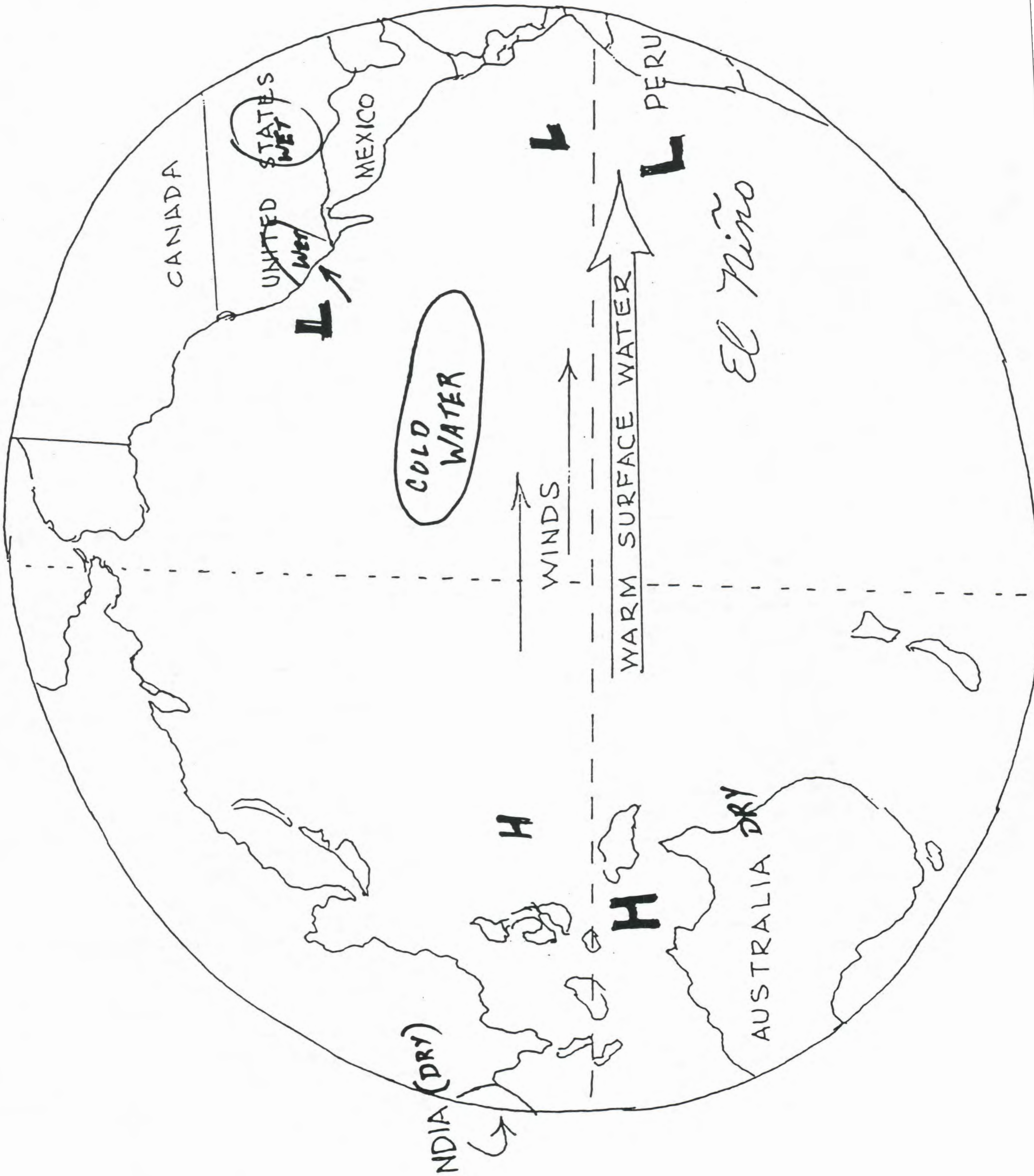
LONG TERM TRENDS
AMES, IOWA

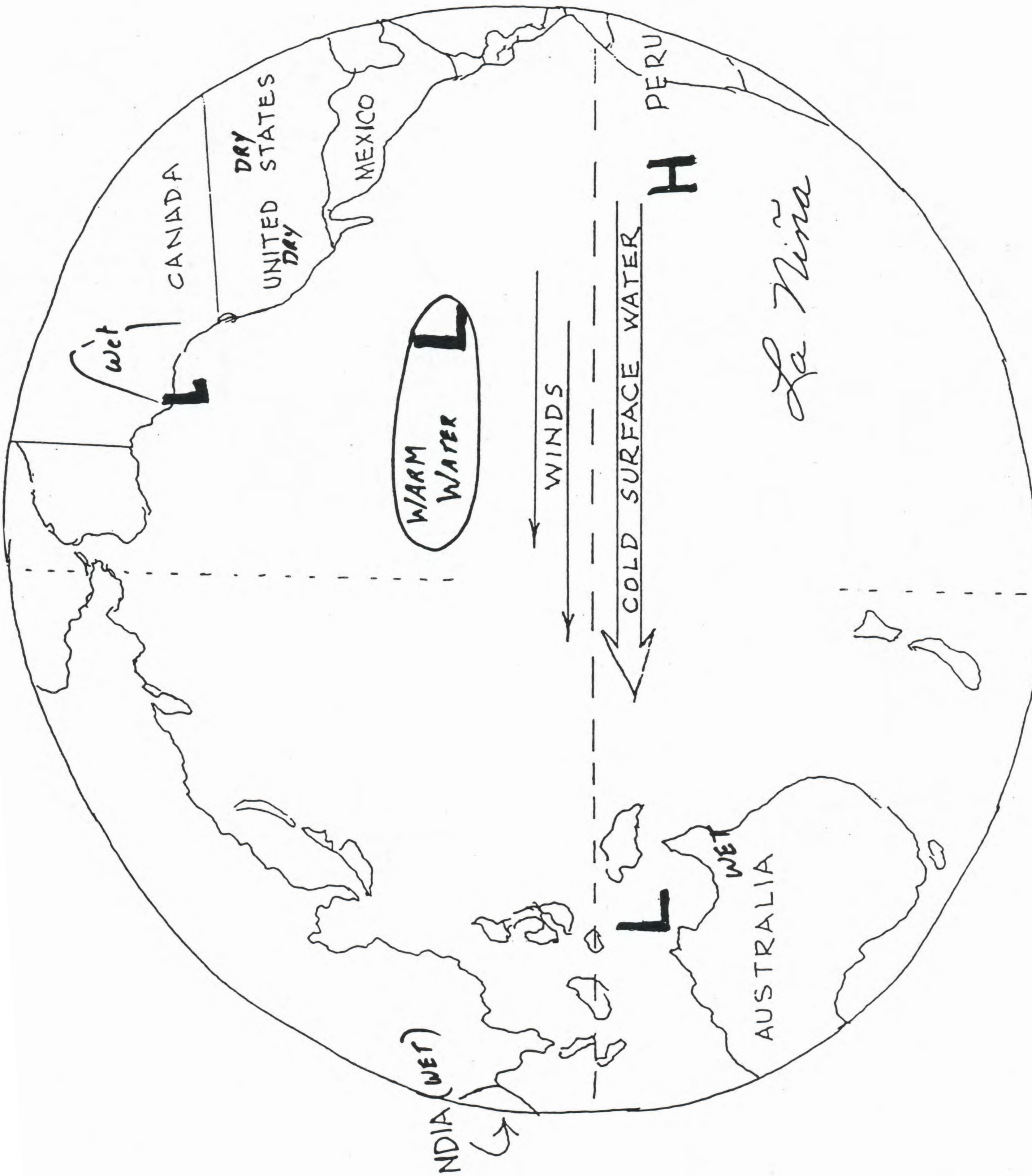


Agricultural Production 18.6 Year Cycle

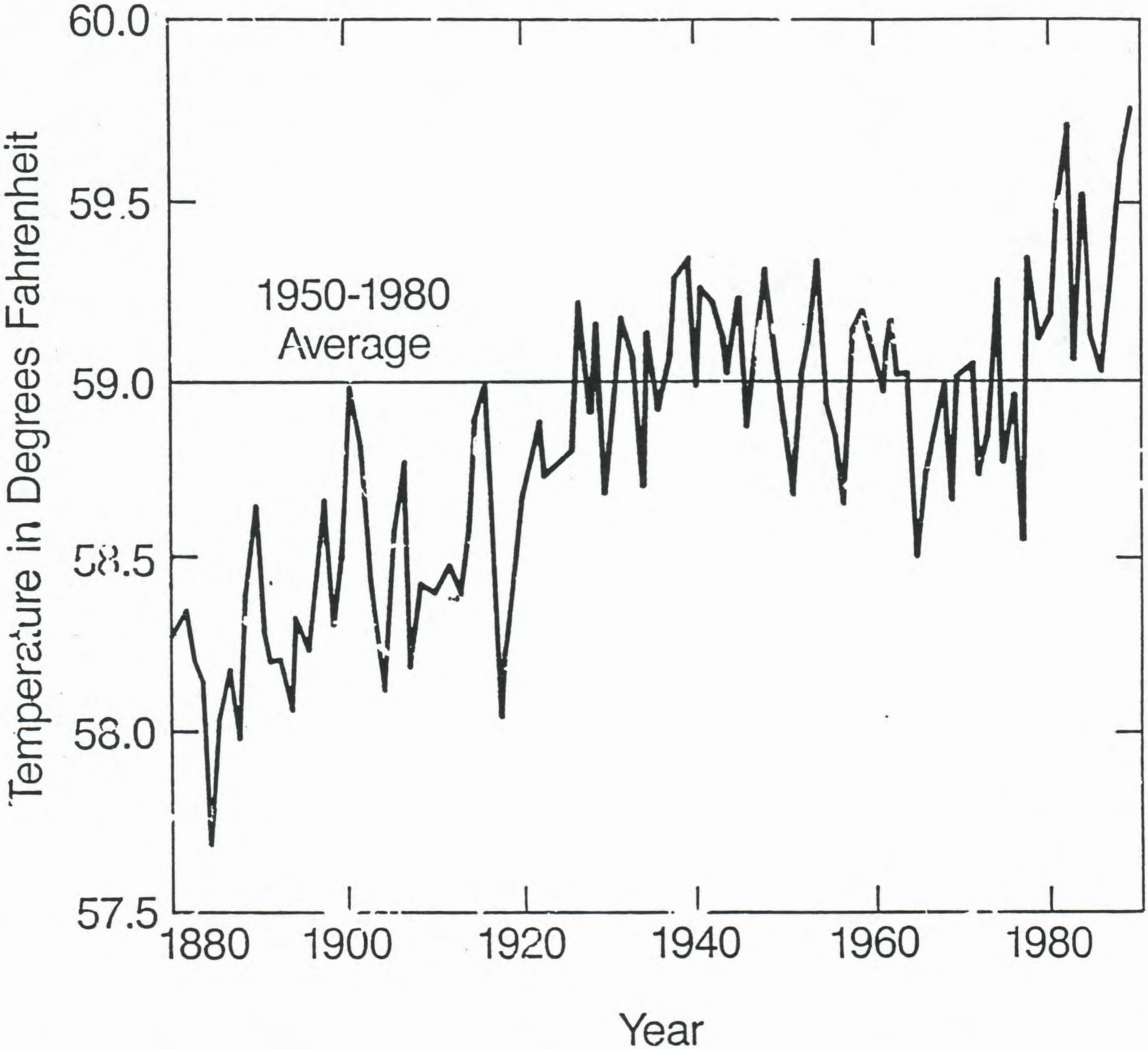
1854	1872	1891	1909	1928	1946	1965	1983	
1855	1873	1892	1910	1929	1947	1966	1984	Uncertain
1856	1874	1893	1911	1930	1948	1967	1985	
1857	1875	1894	1912	1931	1949	1968	1986	
1858	1876	1895	1913	1932	1950	1969	1987	Decline
1859	1877	1896	1914	1933	1951	1970	1988	
1860	1878	1897	1915	1934	1952	1971	1989	
1861	1879	1898	1916	1935	1953	1972	1990	Shortages
1862	1880	1899	1917	1936	1954	1973	1991	
1863	1881	1900	1918	1937	1955	1974	1992	
1864	1882	1901	1919	1938	1956	1975	1993	
1865	1883	1902	1920	1939	1957	1976	1994	
1866	1884	1903	1921	1940	1958	1977	1995	Improvement
1867	1885	1904	1922	1941	1959	1978	1996	
1868	1886	1905	1923	1942	1960	1979	1997	
1869	1887	1906	1924	1943	1961	1980	1998	
1870	1888	1907	1925	1944	1962	1981	1999	Surplus
1871	1889	1908	1926	1945	1963	1982	2000	
	1890		1927		1964			

Fig. 15. Historical periods of weather-related variations in grain production in the Midwest. Periods of shortag include more than half of all wide area droughts. Source: Louis M. Thompson, Cycles, Dec. 1988, 286-2

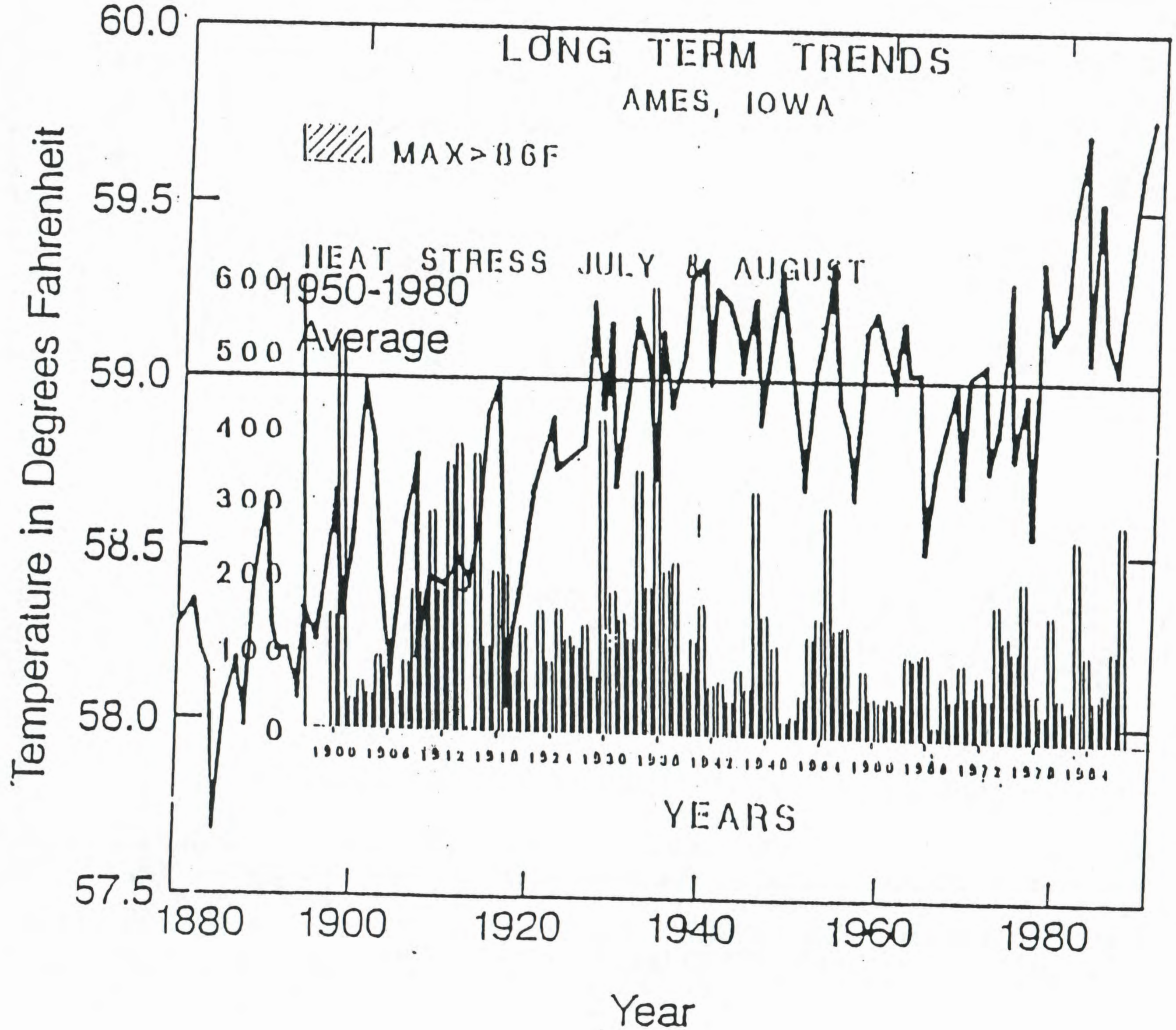

CANADA
UNITED STATES
WET
WET
MEXICO
PERU
L
L
L
COLD WATER
WINDS
WARM SURFACE WATER
El Niño
H
H
AUSTRALIA
DRY
INDIA
(DRY)

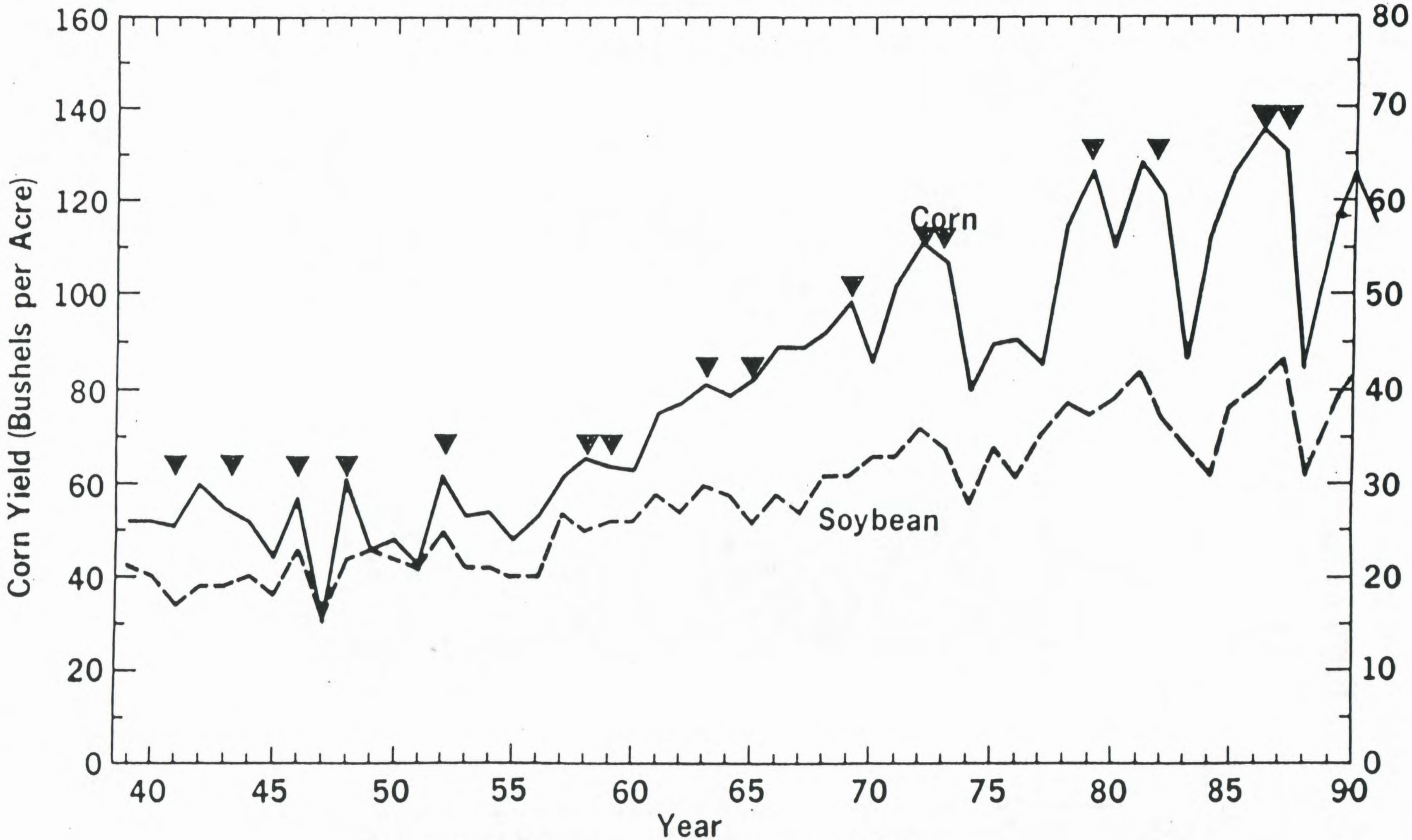

CANADA
wet
UNITED STATES
DRY
DRY
MEXICO
WARM
WATER
WINDS
COLD SURFACE WATER
PERU
La Niña
INDIA
(WET)
WET
AUSTRALIA

Average Global Temperatures



Average Global Temperatures





Annual state corn and soybean yields, Iowa.